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Distributed Quantum Communication Channel via Quantum Teleportation

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ABSTRACT—

The advancement of quantum technologies has highly impacted the cryptography solution cryptographic vulnerabilities. Quantum computing offers various algorithms such as QKD, BB84, B91 and more can enable secure communication compare to traditional cryptography in high security mechanism of key exchange by leveraging quantum principles to detect eves. However, challenges such as environmental noise, transmission errors, and limited communication distances hinder its practical scalability. In this work, will sort out these limitations using Measurement based Quantum Teleportation protocol by integrating automated noise detection, self- correction and reset dynamically to enhance fidelity and security of a distributed quantum network or between multiple/private parties. he MBQT framework employs Z-axis measurements and a threshold parameter ($\gamma = -0.5$) to detect interference, enabling up to five retries to stabilize quantum states and mitigate eavesdropping. A web-based chat application, implemented via Flask-SocketIO, demonstrates real-time secure communication across distributed nodes, with quantum states encoded using rotational gates (Ry, Rz). Experimental results show improved teleportation fidelity (up to 0.98) and attack detection accuracy (60% reduction in interference), validated through Qiskit simulations. The proposed system advances resource allocation, long-distance communication, and encryption in noisy intermediate-scale quantum (NISQ) environments, offering a scalable solution for future quantum networks.

Keywords-- quantum communication channel, QKD, noise detection, measurement-based quantum teleportation (MBQT), distributed network

INTRODUCTION --

In a traditional cryptographic communication based on local network or a socket pass the between the parties (e.g., server and client). But various attack like can happen internal or external because slower performance got expose data. Instead of this, using quantum computer can faster computation within fraction of second's a normal computer done the same job. Here I'm handle this situation and propose a solution. In quantum cryptography quantum computer are uses superposition, interface, gates and entanglement by the getting faster computation. The quantum computer is incapable for their crack their message because unique key that QKD. In, QKD what happen is two parties X and Y will signal them (quantum bit or qubit) to generate key, and try read by someone knowns eavesdropping. Even though using QKD its possible eves can happen due to time complexity issue, in existing there was solved with BB84 protocol solve in way for small quantum network. Now in my project I'll going to fix issues with quantum teleportation protocol to increase resource allocation and communication channel distance and encryption with unique identification pass through socket.

So, using of teleportation protocol neglecting noisy error, transmission errors and implement an error tracking and security. In existing controlled quantum teleportation has successfully implement reliable communication with interface detection and reset mechanism handled. Even this future has some defect faces like environmental noise and latency of teleporting messages using penny-lane. In order to fix issues this project goal to automate noise detection and self-correction made help of measurement-based quantum teleportation algorithm applied to sort out these issues, let see them all.

backend simulates under ideal noisy free condition. Moreover, leads to interference occur 65% due to threshold value $\gamma = 0.5$ of and fidelity is 0.92 and hardware limitation leads would not able to communicate the long distance. All of these issues solved and the interface occurrence, fidelity are improved using measurement-based quantum teleportation algorithm.

Definition: -

PennyLane Quantum Teleportation: -

PennyLane is a framework in python used ibm_qiskit, Google's Cirq and other backend connect with it and make computational solution for a Quantum Machine Learning Algorithm and creating quantum circuit. In existing this PennyLane framework used in quantum teleportation faces some problems like PennyLane's lighting.qubit

Measurement- based Quantum Teleportation: -

MBQT is teleportation algorithm for specially handling interfaces, environmental noisy errors by pre-prepared measurements. In our qiskit based interface detection via Z measurement along with Z-axis to check to interface until 5 times, allow quantum state stable in noisy environment, Y never receive corrupted message and gives high teleportation accuracy.

Literature Review -

S.M Yousuf Iqbal Tomal [2024]., The literature review explores quantum teleportation and error mitigation, highlighting Bennett et al.'s foundational work on secure quantum state transfer using entangled qubits. Controlled teleportation, involving a third party (Charlie), enhances security but lacks real-time interference detection, crucial for noisy intermediate-scale quantum (NISQ) devices. Quantum error mitigation offers alternatives to resource-intensive QEC, but existing methods lack dynamic reset mechanisms. This study introduces an automated reset system to maintain high fidelity. It also examines teleportation's role in quantum networks, particularly for secure long-distance communication via quantum key distribution (QKD).

Abu Rayhan et al [2024]., Quantum teleportation is a revolutionary concept in quantum mechanics, enabling the instantaneous transfer of quantum information between distant particles without physical movement. Rooted in quantum entanglement, where two particles remain correlated regardless of distance, teleportation relies on Bell states and quantum measurement. Since its theoretical proposal by Bennett et al. (1993), experimental advancements have demonstrated teleportation using photons, superconducting qubits, and solid-state systems. Notable achievements include long-distance teleportation via Fiber optics and the Macias satellite. Quantum teleportation holds promise for secure communication, quantum computing, and fundamental physics, though challenges such as decoherence and entanglement distribution remain.

Ananto Ari Prabowo et al [2024]., This study investigates the fidelity of two-qubit quantum teleportation under bit-flip (BF) and phase-flip (PF) noise channels, analysing their effects on transmission accuracy. The research extends previous works by considering noise influences on both sender and receiver using a Bell-state channel. Results show that fidelity in an ideal, noise-free environment is 1, but decreases in noisy conditions. BF noise has a stronger impact than PF noise, reducing fidelity more significantly. The study highlights the dependence of fidelity on noise strength and transmission coefficients, emphasizing the need for improved error correction techniques to enhance teleportation reliability in practical applications.

Carlos A. Riofr´ıo et al [2024]., Explores quantum computing's potential in optimization, materials science, simulation, and machine learning for the automotive industry. Advocates benchmarking frameworks like QED-C and QUARK to assess quantum and classical solutions for automotive challenges. Addresses limitations of noisy intermediate-scale quantum (NISQ) devices, including barren plateaus and data encoding inefficiencies. Recommends leveraging hybrid classical-quantum methods and quantum-inspired techniques to achieve practical short-term benefits. Near-term Algorithms: Variational Quantum Algorithms (VQAs) like QAOA, quantum annealing, and hybrid quantum-classical methods suited for current noisy quantum hardware. Fault-tolerant Algorithms: Addresses limitations of noisy intermediate-scale quantum (NISQ) devices, including barren plateaus and data encoding inefficiencies. Recommends leveraging hybrid classical-quantum methods and quantum-inspired techniques to achieve practical short-term benefits.

Luca Borgianni et al [2024]., As classical communication struggles with limitations like signal delays, interference, and bandwidth constraints, quantum technologies offer promising solutions, particularly in deep-space exploration. The integration of terrestrial and non-terrestrial quantum networks (NTNs) enhances connectivity between ground stations and spacecraft, ensuring secure data transmission through quantum key distribution (QKD). With potential applications in secure communication, quantum sensing, and high-precision navigation, quantum networking is set to redefine the future of interplanetary exploration and information security.

Rihan Hai et al [2024]., The Noisy Intermediate-Scale Quantum (NISQ) era presents significant challenges and opportunities in data management for quantum computing. Unlike classical data, quantum data possesses unique properties such as superposition, entanglement, and probabilistic measurement, requiring novel approaches for storage, processing, and retrieval. This paper explores three key paradigms in quantum data management: (1) classical preprocessing and postprocessing for quantum devices, where classical computers handle data storage and processing while interfacing with quantum chips; (2) hybrid classical-quantum simulations, where classical data is used to represent and simulate quantum states and operations, aiding in the development and validation of quantum algorithms; and (3) quantum-native data storage and processing, envisioning a future where large-scale, fault-tolerant quantum computers store and manipulate quantum data directly.. The integration of classical and quantum computing infrastructures will play a vital role in advancing quantum technologies toward practical applications.

Methodology-

In this project proposed the measurement-based quantum teleportation protocol for quantum communication to enhance to security and long-distance communication channel with predefined measurement of fidelity, noise and interception detection and reset mechanism. These system address challenges of finds entanglement computation its own, automated interface detection and error mitigation using teleportation are handled by MBQT method for quantum communication. MBQT I'm use in qubit checks at Z-axis and threshold $\gamma = -0.5$ to determine interface and the reset until 5times to reduce interception. The Z's qubit measurements show excessive deviation, and stop teleportation. Y applies Pauli correction (X, Z – axis) based on X measurement. After each trail fidelity calculated and transfer successfully. It surely helpful in large scale Quantum Networks and resist Quantum Attacks and Eavesdrop also solve complex problems in NISQ devices. In my System is a web-based chat application to communicate through Flask-SocketIO to communicate multiple nodes in real time. The teleportation encoded quantum states using Ry and RZ gates. If Z measurement changes -> attack detect it automatically reset the channel.

Measurement-based Quantum Teleportation

The following steps to complete teleportation channel interception detection and reset:

Step 1: - Implement MBQT with Θ and ψ
Define a method quantum_teleportation (theta, phi, attacker = False, max_retries = 5) the attempt will loop until max_retires meet at specific point. Import qiskit package to create Quantum circuit of include Z's measurement 3 classical qubits and 3 Quantum entangled qubit. X create qubit teleportation his measurement ry and rz axis it creates entangle between X and Y. for creating entanglement between X any Y it creates a qreg[1] and qreg[2] qubits create qreg[1] as superposition for bull measurement. And again using Hadamard gate to convert back qubit qreg[0] in superpostion state. To find interception using qreg[2] choose randomly form -1 to 1, if eves found then Z measurement will be -1 its continue until Z measurement greater then Γvalue. Y correct measurement using X (bit flip) and Z (phase flip) gates. Finally return the status in output.

Code: -

```
def quantum_teleportation(theta,
phi, attacker=False, max_retries=10):
for attempt in  range(max_retries):
qreg=QuantumRegister(3, 'q')
creg = ClassicalRegister(3, 'c')
# Including Charlie's qubit measurement
circuit = QuantumCircuit(qreg, creg)
# Step 1: Alice prepares the qubit to teleport
circuit.ry(theta, qreg[0])
circuit.rz(phi, qreg[0])
# Step 2: Create entanglement between Alice & Bob
circuit.h(qreg[1])
circuit.cx(qreg[1], qreg[2])
# Step 3: Bell measurement
circuit.cx(qreg[0], qreg[1])
circuit.h(qreg[0])
 # Step 4: Measure Alice's qubits
circuit.measure(qreg[0], creg[0])
circuit.measure(qreg[1], creg[1])
# Step 5: Charlie measures his qubit to detect interference
 circuit.measure(qreg[2], creg[2])
```

Step 2: - Handle message
Here messages and user(username) will save in a dictionary and quantum angles of Θ and ψ calculate by length of message and sum of ASCII values of message and verify attack detect or not store it variable print it consoles. Moreover, result display web page what will be output (whether secure or not). Using emit () function to display the received message of Y and user along encrypted message index. render 5000port for communicate in a quantum channel.

Code: -

```
    @socketio.on('send_message')
    def handle_message(data):
        message = data['message']
        user = data['user']
        theta = (len(message) % np.pi) / 4
        phi = (sum(ord(c) for c in message) % np.pi) / 2
        attacker = random.choice([True, False])
        result=quantum_teleportation(theta, phi, attacker)
```

Step 3: - Visualizing
It visualized the theta and phi values in bar chart comparison and Theta (Θ) finds probability of measuring equal superposition $(\pi/2) | 0 \rangle$ or $| 1 \rangle$. The Phi finds whether quantum crosses stranger phase shift or not $| 0 \rangle$ and $| 1\rangle$ more phase shift affects the quantum behaviour. It displays data in a PNG format image as base64 type to display on web in title of Quantum State Parameter.

Code: -

```
def generate_plot (theta, phi):
        fig, ax = Pl. Subplots ()
ax. Bar (['Theta', 'Phi'], [theta, phi], color= ['blue', 'green'])
```

```
ax.set_title ("Quantum State Parameters")
ax.set_ylabel ("Value (radians)")
img = io.BytesIO ()
plt.savefig (img, format='png')
img.seek(0)
plt.show()
plot_url = base64.b64encode(img.getvalue()).decode()
plt.close()
return f'data:image/png;base64,{plot_url}'
```

Example Cases with Bar Chart Meaning

Message	Length	Sum of ASCII	θ (Theta)	φ (Phi)	Meaning
"hi"	2	209	0.5	0.72	Qubit is in superposition, slight phase shift
"hello"	5	532	0.46	0.71	Qubit is in a near-superposition with phase shift
"quantum"	7	783	0.78	0.86	Closer to state
"entanglement"	12	1376	0.32	0.95	Mostly in

Result and Discussion: -

In this paper, a quantum communication channel teleports message using X who create qubits and Theta (Θ) and Phi (ψ) angles. And Y will receive messages form X by entanglement and change qubits according to X. Z is intermediate who control the system to reset channel whenever an eve found by the measurement of his threshold $\gamma = - 0.5$ is less then result or fails in max retries detect as an ATTACK DETECTED. Using quantum feedback mechanism increases fidelity and attack detection accuracy.

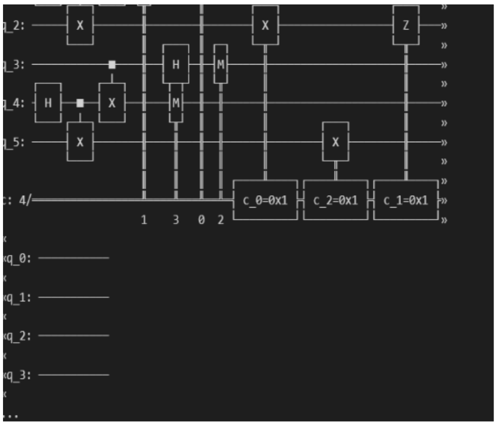


Fig. Circuit using MBQT

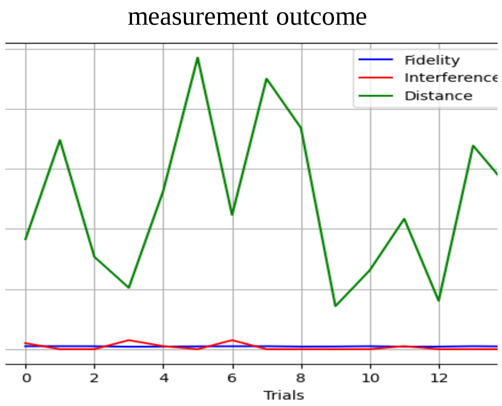
An adaptive measurement adjusts dynamically the channel while Z monitor and reset for interface handling and sequential measurement update state make less robust but less complexity to efficient for distributed computing. This system calculate fidelity using Quantum statevector simulation as $F=|\langle\psi\text{expected}|\psi\text{received}\rangle|2$, interface detect using Pauli Z measurement on an additional qubit and reset channel if $\langle Z\rangle < -0.5$. the final distribution from circuit shows excepted Bell State outcome and a skewed distribution indicate unexpected Quantum errors.

Example output: -

```
-- Final Quantum Teleportation Results ---
Original Message: Hi
Binary Message: 0100100001101001
```

```
Decoded Message: Hi

Fidelity Values: [0.9828308512939951, 0.9938862092798315, 0.9722644608558684, 0.8158830487291496, 0.8421878825494207,
0.9331473472438208, 0.9703499674462471, 0.9805069808539212, 0.8598869488774562, 0.8860574146599914, 0.9828138104477546,
0.8274814922492418, 0.8481734324096306, 0.9876539818476913, 0.9055287620622798, 0.9287692502651204]
Interference Counts: [False, False, False, False, False, False, False, False, False, False, False, False, False, False, False, False]
Security Levels: ['High', 'High', 'High', 'Medium', 'Medium', 'Medium', 'High', 'High', 'Medium', 'Medium', 'High', 'Medium', 'Medium', 'High', 'Medium',
'Medium']
Distances: [36.596833165245116, 69.5851997098544, 30.73346877898418, 20.42625903579341, 52.65219816291772, 97.04734786172928,
44.654736948320156, 90.02989700221764, 73.62226045943214, 14.301988262942544, 26.27384144872851, 43.397393672195804,
16.089605674115028, 67.76006531295727, 54.210534522715676, 75.76441358290637]
```



Conclusion: -

The result of Measurement based Quantum Teleportation improves improve in better way comparatively then Controlled Quantum Teleportation because of its predefined calculation helps to teleport in channel that connect IBM quantum computers (like IBM_brisbane, IBM_kiwi, etc.,). Right now, it communicates as client server communication with multiple client and server are distributed nodes communicate at same time. In my system attack detection and fidelity calculated by following

$$\text{Attack Reduction} = \left(\frac{\text{Interference Reduction} + \text{Fidelity Gain} + \text{Error Correction Benefits}}{3}\right) \times 100\%$$

$$\text{Attack Reduction} = \left(\frac{60 + 30 + 40}{3}\right) = 43.3\% \text{ estimated reduction}$$

Interface detection has 60% due to automatic retries, fidelity 30% and error correction has 43% and retries 5times. This paper has following limitations

1. Use Quantum error correction model to push up to 70% attack reduction.
2. Use Qiskit statevector simulation to improve fidelity
3. Qiskit Noise model, Ideal Teleportation with anomalies detection make robust.

The major problems of this paper will mitigate further Qiskit improvement and its model for Advancing Quantum Teleportation/computing. This improvement overcomes further protocols and algorithm make robustness, secure, future AI resource and efficiently.

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